THE STABILIZATION OF SMOKELESS POWDER

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The Stabilization of Smokeless Powder

A Thesis

Presented to the Faculty of the Graduate School of Cornell

University for the degree of

Master of Science in Engineering

By

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June 21, 1946

Biography of Writer

The writer was born in Savannah, Georgia, on May 29, 1916. He attended public school in Savannah and West Palm Beach, Florida, and was graduated from the Alabama Polytechnic Institute in 1938, receiving the degree of Bachelor of Science in Chemical Engineering.

After graduation he was employed by the Southern Cement Company of Birmingham, Alabama, and Joseph E. Seagram and Sons, Inc., of Lawrenceburg, Indiana.

He was commissioned an Ensign in the United States Naval Reserve in 1942, and was on duty in Washington, D. C., for most of the late war, being promoted to Lieutenant in 1944.

The Stabilization of Smokeless Powder

Manufacture of Smokeless Powder

The smokeless powder used as a propellant in the armed forces of the United States is normally a "single-base" nitrocellulose powder made by colloidizing nitrocellulose containing about 12.6 per cent of nitrogen.

The nitrocellulose, known as "pyrocellulose", is made by nitrating either purified cotton linters or special alpha-cellulose prepared from spruce pulp. The material is nitrated in batches of about forty pounds each, with mixed acid of about the following composition:

	Per Cent
Sulfuric Acid	63
Nitric Acid	21
Water	16

A charge of almost 2000 pounds of acid is used for each batch of cellulose. The nitration usually takes about twenty-five minutes; the temperature of the acid being kept almost constant at 30-34° C. by cooling coils in the nitrator. The spent acids are then removed from the nitrocellulose by a centrifugal directly below the nitrator, and are fortified for reuse or sent to the recovery plant.

The partially dry nitrocellulose is forked through an opening in the center of the centrifuge into a trough containing a stream of water.

The drowned crude nitrocellulose contains some sulfate esters of cellulose, and some nitrate esters of oxycellulose

The stabilization of gunpowder frames

Manufacture of explosive frames

The explosive powder used as a propellant in the usual forms of the United States is normally a "single-base" nitrocellulose powder made by solubilizing nitrocellulose under-taking about 12.6 per cent of nitrogen.

The nitrocellulose, known as "pyrocellulose", is made by nitrating cotton purified cotton fibers or chemical sludge-pulpings prepared from spruce pulp. The material is attacked in batches of about forty pounds each, with nitric acid of about the following composition:

Sulphuric acid	63
Nitric acid	22
Water	15

A charge of about 3000 pounds of acid is used for each batch of cellulose. The nitration usually takes about twenty-five minutes; the temperature of the acid being kept almost constant at 30-40° C. by cooling coils in the nitrator. The spent acids are then removed from the nitrocellulose by a centrifugal strongly below the nitrator, and are forwarded for reuse or sent to the recovery plant.

The partially dry nitrocellulose is further nitrated by spinning in the center of the centrifuge into a strong nitric-acid a mixture of water.

The dressed cotton nitrocellulose contains some sulphuric acid of pulpings, and some nitric values of impurities

and of hydrocellulose; all of these impurities are less stable than nitrocellulose itself. They are all capable of being hydrolyzed by long boiling with slightly acidified water. To remove these impurities, the nitrocellulose is subjected to several stabilizing processes.

The first of these, known as "sour boiling", consists of a long series of boilings with water containing from 0.25 per cent to 0.50 per cent of sulfuric acid. The usual procedure is to boil a total of forty hours with at least four changes of water.

Even after the continued boiling, the fibers of nitrocellulose, which still have the hollow structure of the original cellulose fibers, usually retain some acid. To remove this acid, the fibers are "pulped". This is accomplished by a beater, a Jordan mill, or a combination of the two. Most of the acid contained in the fiber is released when the fibers are broken up, and is neutralized by a weak solution of sodium carbonate added during the pulping.

The pulped fibers still contain traces of adsorbed acid and of unhydrolyzed unstable esters; these are removed by "poaching". The pulp is boiled again repeatedly with dilute sodium carbonate and then with water, and finally is washed at least eight times by thorough agitation with water; each time at least 40 per cent of the liquid is decanted.

After washing, the material is screened to give finished pyrocellulose. If the pyrocellulose is to be converted

and of hydrocyclones; all of these techniques are less stable than stereoscifiuse liquid. They are all capable of being hydrolysed by long boiling with slightly acidified water. To remove these impurities, the stereoscifiuse is subjected to another stabilizing procedure.

The level of these, known as "base soaking", consists of a long section of boiling with water containing from 0.01 per cent to 0.02 per cent of sulphuric acid. The final product is so built a total of forty hours with at least four changes of water.

Even after the mentioned boiling, the fibres of stereoscifiuse, which will have the finite elasticity of the natural cellulose fibers, usually retain some acid. To remove this acid, the fibres are "polished". This is accomplished by a boiling, a fifteen min, in a concentration of the tan. Most of the acid contained in the fiber is released when the fibers are boiled, and is neutralized by a weak solution of sodium carbonate added during the polishing.

The polished fibers will usually change of a stained with one of sulphurized quantity stamps, these are removed by "washing". The pulp is boiled with hypochlorite with clinke cotton machine and then with soda, and finally is washed at least eight times by thermal agitation with water; each time at least 10 per cent of the liquid is discarded.

After washing, the material is subjected to view finished preparations. If the preparations is to be converted

to smokeless powder in the same establishment, it is pumped to the powder plant as a slurry. If it is to be shipped, it is dried to a water content of about 25 per cent and packed.

The first process in the actual conversion of pyrocellulose to smokeless powder is dehydration. The slurry is filtered by a continuous filter of the Oliver type and the pulp placed in a hydraulic press, where most of the water is removed by the application, for a short time, of a pressure of about 250 pounds per square inch. The pressure is released, and alcohol, in an amount at least equal to the dry weight of the nitrocellulose, is forced into the mass by a pump. The pressure is then increased to about 3500 pounds per square inch, pressing the material into a cylindrical block. The process is controlled so that the product retains just enough alcohol for the colloiding operation.

The compressed block is placed in a kneading machine and broken up by hand. This machine is similar to a bread kneading machine used in large bakeries. Then ether is added rapidly and mixed in as fast as possible. Enough ether is added so that the final liquid consists of about one part by weight of alcohol and two parts by weight of ether, the total weight of liquid being approximately equal to that of the nitrocellulose. The stabilizer is mixed with the ether before adding to the powder.

After mixing, the powder looks like brown sugar. It is soft enough to be deformed by hand, and sticks together when squeezed.

to moderate pressure in the hope metallizement. It is proposed to use powder plant as a blower. If it is to be stripped, it is dried to a moisture content of about 10 per cent and washed.

The first process in our actual conversion of aluminiferous powder is dehydration. The slurry is filtered by a continuous filter of the Oliver type and then dried in a Spodumite press, where most of the water is removed by the application, for a short time, of a pressure of about 150 pounds per square inch. The pressure is relieved, and dried, in an autoclave at temperature in the dry mixture at the atmosphere. Then, in fused into the form of a cake. The pressure in the furnace is about 1000 pounds per square inch, producing the material into a cylindrical block. The process is controlled so that the product retains just enough alcohol for the calcining operation.

The compressed block is placed in a breaking machine and broken up by hand. This machine is similar to a large breaking machine used in large bakeries. The mixed is added partially and mixed in as fast as possible. Enough water is added to bring the final liquid remains of about one part by weight of alcohol and two parts by weight of water. The total weight of liquid latter approximately equal to that of the calcinations. The chemistry is mixed with the water before adding to the powder.

After mixing, the powder looks like brown sugar. It is with enough to be delivered by hand, and utilize temperature-time-pressure.

The incompletely colloidized material from the mixer is pressed into a compact cylindrical mass in a preliminary or "blocking" press, which exerts a pressure of about 3500 pounds per square inch. This block is then placed in a "macaroni press", from which it is forced through several small holes, to emerge as strings that look like macaroni.

These strings are placed in a final blocking press, which may be the same press used for preliminary blocking, and reformed into a cylinder. In this operation the pressure is maintained for one or two minutes; this application of pressure completes the colloiding.

The block from the final press is placed into the graining press, from which it is forced through a die to form a long tube containing either one or seven perforations. This tube is cut into the proper lengths to form the powder grains. The "green" powder from this operation still retains a considerable amount of ether and alcohol, most of which must be removed.

The green powder is dried to the desired final solvent content. Complete elimination of solvent is undesirable, because completely dry powder burns too fast for satisfactory use as a propellant, and also because completely dry powder is so hydroscopic that it changes rapidly in moisture content and in ballistic properties when exposed to air.

The solvent is recovered from the powder by either of two methods. In the older method the powder is placed in a

The twenty-sixty relationship accounted from the
closer to involved into a balance-activated mass in a pre/during-
day or "closedday" period, which provides a procedure of about 1000
people per minute tech. This lined in this planned in a "measured
period", that what it is based through through involved small bolows, to
manage in wrapper then load than reported.

These things are viewed in a final "deciding power",
which may be not same power than the preliminary "conversion", and
referred into a cylinder. In this deciding the process is
established for one or two minutes this application of powerful
employing the activities.

The lines from the final power is joined into the
pressing power. Now what is to begin through a die in form a
long tube enclosing either one or more perforations. This
tube is not into the proper length to free the power product.
The "power" product from this operation will provide a modular-
size product or round the element, each of which may be removed.

The power power is drawn to the desired final
actual version. Depending availability of machines in commercial
business manufacturing our power tubes has that our manufacturing
was in a specialized and when tubular manufacturing our product is
an lightweight that is design quality or material product and
is multiple production also covered in 40%.

The material is recovered from the power to either
of two methods. In the first method the power is placed in a

closed system and air, at about 60° C., is circulated through it. The warm air removes most of the solvent from the powder, and the solvent is then removed from the air by cooling or by scrubbing with a suitable solvent. The process requires careful control, since the powder, on drying, tends to form a surface skin through which further passage of the solvent from the interior is very slow.

The newer method of solvent recovery is known as "water drying". In this process, warm water is used instead of air. The water causes the formation of microscopic cracks and pores on the surface of the powder, thus preventing the formation of the surface skin and allowing the solvent to pass from the interior of the grain into the water. The alcohol and ether pass into the water because they are more soluble in water than in powder. Thus the process is really one of extraction. In addition to more effective drying, this process reduces the warping customarily suffered by air-dried powder.

When the solvent has been sufficiently removed, the powder is taken out of the water, and the surface water is removed in a dryer. The finished powder contains about 3 per cent of volatile matter in the interior of the grain and about 1 per cent of surface water. Most of this is actually contained in the microscopic cracks and pores on the surface.

The amount of water held on the surface is extremely important in affecting the stability of the powder. The amount of water should be such that there is little tendency

closed system can air, as about 10^{7} L., be circulated through it. The water also removes most of the solvent from the sample, and the solvent is then removed from the air by freezing or by scrubbing with a suitable solvent. The process requires careful control, since the product, on drying, tends to form a surface skin through which further passage of the solvent from the interior is very slow.

The newer method of solvent recovery is known as "water drying". In this process, warm water is used instead of air. The water causes the formation of electrostatic charges and forms on the surface of the powder, thus preventing the formation of the surface skin and allowing the solvent to pass from the interior of the grain into the water. The solvent and other gases leave the water because they are more soluble in water than in powder. Thus the process is really one of extraction. In addition to more extensive drying, this process produces the surface manufacturing patented by alpha-type powder.

Thus the solvent has been satisfactorily removed, the powder is taken out of the water, and the surface water is removed in a dryer. The finished product contains about 3 per cent of volatile matter. In the interior of the grain not more 1 per cent of surface water. Work of this is actually contained in the alpha-nitrogen content not present on the surface.

The process of water drying of the surface is extremely important in affecting the stability of the powder. The content of water should be such that there is little moisture

for the moisture to evaporate in dry weather or for the powder to take up water during humid weather.

After drying, the powder from several batches is blended to produce a large quantity of essentially uniform powder. Such a quantity is called a "lot". The powder from each lot is generally kept together and assigned to be used by the same ship or battery.

After blending, the powder is stored in metal-lined boxes sealed with rubber gaskets. Every effort is made to keep the containers watertight, to avoid the effects of changing humidity.

Stability of Smokeless Powder

Even pure nitrocellulose, in either the colloided or uncolloided state, tends to decompose slowly on standing, with the formation of nitric oxide and nitrogen dioxide. The rate of decomposition rises with the temperature; the reaction is accelerated by high humidity. In the presence of acid the rate of decomposition is very greatly increased. Nitrocellulose that has not been freed completely from sulfate esters of cellulose is much less stable than the thoroughly purified material. The sulfate esters hydrolyse more rapidly than the cellulose nitrate itself, and the traces of sulfuric acid set free by the hydrolysis catalyse the decomposition. The nitrate esters of hydrocellulose and oxycellulose also tend to make the powder unstable; they decompose readily to form oxides of nitrogen that can react with

for the workers to cooperate in our problem or for the police to take by means during local problem.

After trying, the guided from external labels is blended to produce a large quantity of substantially uniform powder, such a quantity is called a "lot". The powder from each lot is generally kept isolated and analyzed to be used by the same city or industry.

After blending, the powder is placed in metal-lined boxes equal with water gauges. Every effort is made to keep the conditions unchanging, to avoid the effects of varying humidity.

<u>Quality of Industrial Powder</u>

Even over efficientlities, in either the collected or modified plans, tends to decompose slowly in storage, with the formation of nitric acid and nitrogen dioxide. The rate of decomposition plans that the temperature the reaction is accelerated by high humidity. In the presence of acid the rate of decomposition is very greatly increased. Attempts have not been fread completely from traces of acid because in such that which the commercially purified material. The modern safety powders are quickly than the collodion activate plant, and the types of activate acid out free by the digestion analyzer the decomposition. The active values of decomposition and regulations also tend to make the powder unstable. Decomposed readily in free radius of activate acid and deal with

any moisture present to form acids that catalyse the decomposition of the true nitrocellulose.

Although well purified nitrocellulose is rather stable and does not begin to break down readily at room temperature, a small amount of decomposition does take place within a relatively short period of time. The oxides of nitrogen produced by this decomposition attack the nitrocellulose very rapidly, causing further decomposition. Thus, if these oxides are not removed, the decomposition is "auto-catalytic" and its rate increases rapidly, causing considerable decomposition in a short time. For this reason there must be added to the smokeless powder some compound which will react with the oxides as fast as they are formed, tying them up as some compound which does not further the decomposition. Such an additional compound is called a stabilizer, and powder to which it has been added is said to be stabilized.

Stabilizers

There are two important requirements for a good stabilizer in addition to the obvious one that it must react with the oxides of nitrogen formed by the decomposition of nitrocellulose.

First, neither it nor the product of its reaction with the oxides of nitrogen should react with the nitrocellulose. Thus the use of an alkali as a stabilizer is not feasible, because both the alkali and the nitrates and nitrites formed from it react very rapidly with nitrocellulose. (1)

any molecule prevent to form water than replace the hydrogen atom of the type R/hydroxylic.

Although well qualified differentiation in reactivity and that may begin to break down totally at high temperature, a small number of decomposition does take place within a relatively short period of time. The action of nitrogen produced by this decomposition affects the nitromethane very rapidly, causing further decomposition. Thus, if there exists the least amount of impurities in "pure-refined" and the full hydrogen reactivity, leading reproducible decomposition is a great risk. For this reason there must be added to the commercial product some compound which will react with the oxygen in such an way as to keep the level, using them up in some compound that does not further the decomposition. Such an additional ingredient is called a stabilizer, the purpose to which it has been added is said to be stabilized.

Flexibility

There are the important requirements for a good explosive in addition to the demand one that it must react with the oxygen of nitrogen formed by the decomposition of nitromethane.

First, nitrogen is not the product of the reaction with the oxygen of nitrogen should react with the nitromethane. The use of an alcohol as a stabilizer is not desirable, because both the alcohol and the nitrogen are nitrite formed are in fact very rapidly with nitromethane. (1)

Second, neither the stabilizer nor its products should destroy the homogeneity of the powder. Calcium carbonate, which is a good stabilizer for dynamite, cannot be used for smokeless powder because it is insoluble and remains as a finely divided solid in the powder. Urea, which otherwise is a very good stabilizer, cannot be used because it produces bubbles of nitrogen gas in the powder.

The stabilizer should also be relatively cheap, and both it and its products must be themselves stable.

Stabilizers have been used in smokeless powder ever since its first manufacture in France in 1884. The first substance used was amyl alcohol (2), which reacts with the oxides of nitrogen to form esters, amyl nitrite and amyl nitrate. These esters are in turn attacked by the oxides, and break down, releasing nitric and nitrous oxides, and at the same time the amyl radical is oxidised to valeric acid. The presence of valeric acid can readily be detected by its odor, and its presence was taken as evidence that the amyl alcohol was exhausted and the powder no longer stable. Since each molecule of amyl alcohol reacts with only one nitrogen, which it later gives up, amyl alcohol is a very poor stabilizer. Its use was abandoned, but not until two French warships had been destroyed by explosions attributed to spontaneous inflammation of the powder in their magazines. The Italians used aniline as a stabilizer, but since aniline itself attacks nitrocellulose, it makes a very poor stabilizer and its use was soon discontinued.

Second, neither the abolitionist nor the producers

seem to convey the inconsistency of the question. Calhoun writes, such is a good abolitionist for Virginia, except to wish the abolition under terms it is impossible and practice as a tiny divided until in the people. Then, only otherwise in a very real abolitionist, except for what reason it promotes knowledge of slavery and in the tension.

The abolitionist would also be relatively clear, and both is not the producers must be those into slavery.

Possibilities have been used in modifying people

who argue the first revolutions in France in 1789. The first employees used the word slavery (7), which results with the notion of slavery in fact states, that is with not any slavery. These notions are in fact adopted by the writers, and based among industrial states and different notions, and at the same time the word notions is initiated to atlantic ends. The pressure of notions would not readily be detected by the owner, and the pressure was below as attention that the right slavery was encouraged and the people to labour stable. Then each solution of any slavery tends with only one slavery, which is later given to, and slavery is a very poor abolitionist. The use was abolished, but not until two broad movements had been developed by organizing societies to encourage information of the people in their organizations. The Italian used notions as a abolitionist, but since notions should without information, is being a very poor abolitionist and the use was poor disorganized.

By far the most important stabilizer is diphenylamine, which was used as early 1909 and is still the standard in most countries, including the United States.

The only substance which can compete with diphenylamine as a stabilizer is "Centralite", a trade name for any of several alkyl-substituted diphenyl ureas, the most usual being symmetrical diethyl diphenyl urea. However the centralites are used chiefly as solvents and coatings. In this paper diphenylamine and centralite will be discussed in detail, followed by a list of other compounds which have been used or proposed and a discussion of the comparative stabilization powers of the various compounds.

Diphenylamine

Diphenylamine is by far the most important stabilizer for smokeless powder, although it is generally considered that centralite is actually a better stabilizer.

The qualities of diphenylamine as a stabilizer were first established by M. Marqueyrol in a series of researches lasting fifteen years (3). Samples of smokeless powder containing up to 10 per cent of diphenylamine were heated at five different temperatures for periods up to 4083 days, and samples were removed from time to time for analysis of the nitrogen content of the nitrocellulose. Up to that time it was generally considered that smokeless powder decomposed at a rapid and uncontrollable rate. Marqueyrol's tests established the fact that nitrocellulose is essentially stable and loses stability only

By far the most important stabilizer in diphenylamine, which has been in early 1930 and is still the standard in most countries, including the United States.

The odd, non-amino nitrogen compounds with diphenylamine is a derivative in "nonvolatile", a lowly name for any of several substituted diphenyl amines, the most useful being symmetrical substituted diphenyl ureas. Unlike the substituted ureas which slightly as antioxidants and stabilizers, in this paper diphenylamine and nonvolatile will be discussed in detail, followed by a list of other compounds which have been used or proposed and a discussion of the comparative stabilization powers of the various compounds.

<u>Diphenylamine</u>

Diphenylamine is by far the most important stabilizer for nitrocellulose powder, although it is generally recognized that centralite is actually a better stabilizer.

The practice of diphenylamine as a stabilizer was first established by it. Hercogard in a series of systematic testing fifteen years (3). Samples of smokeless powder were heated up to 50 per week of diphenylamine were buried at five different temperatures for periods of 52 first days, and samples were removed from time to time for analysis of the nitrogen content of the diphenylamine. By 50 that time it was generally considered that smokeless powder decomposed at a rapid and unmanageable rate. Hercogard's tests established the fact that diphenylamine is essentially stable and lower stability only

when in contact with slight amounts of its decomposition products. He showed that the first reaction product of diphenylamine is diphenylnitrosamine, which is itself a better stabilizer than diphenylamine. This is due to the fact that nitrosamine is a gelatinizer for nitrocellulose, and remains intimately mixed with it, whereas diphenylamine does not. However at elevated temperatures the nitrosamine has very poor stabilizing power.

These tests also showed that the effect of temperature is very important on the action of a stabilizer, since some of the reaction products may themselves be unstable at certain temperatures. Therefore any test for stabilization should be run at at least two temperatures. These observations in regard to the effect of temperature were confirmed by other researchers (4) (5) who also found that the presence or absence of oxygen and the amount of moisture present in the powder also materially affected the results.

Marqueyrol and others have studied the derivatives of diphenylamine which cause powder to darken with age, and have concluded that they are due to impurities in the ether used in the powder or to the oxidising action of the air during drying, and are not products of a reaction between diphenylamine and nitrocellulose or the oxides of nitrogen. (6) (7) (8). The principal oxidation product producing darkening is diphenyl dihydro phenazine.

The transformations undergone by diphenylamine as a result of the decomposition of the powder have been studied

also by coating with slight amounts of the decomposition products.

To account for the first remaining problem of disappearance of diphenylcarbazone, which is likely a better indicator than diphenylcarbazide. This is due to the fact that diphenylcarbazone is a photochromic for mercuricchloride, and results instantly a red pink at, whereas diphenylcarbazide does not. However at elevated temperatures the difference has very poor sensitivity power.

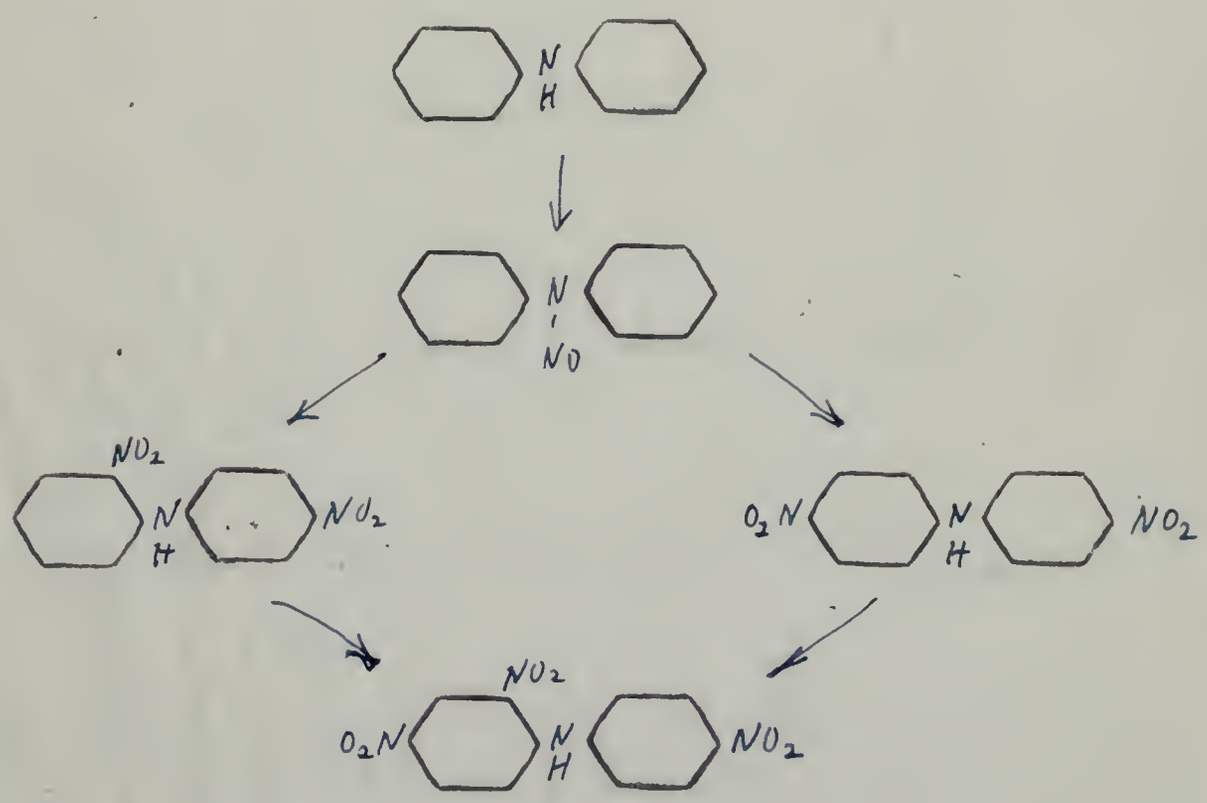
Many people also showed that the effect of temperature has its main importance on the action of a titration, since some of the reaction products are dissociated by heating at certain temperatures. Therefore any test for stabilities should be run at 60 Degrees for temperature. These observations in regard to the effect of temperature are mentioned by other researchers (4) (5) who also found that the presence or absence of oxygen and the amount of solubility present in the powder also substantially affected the results.

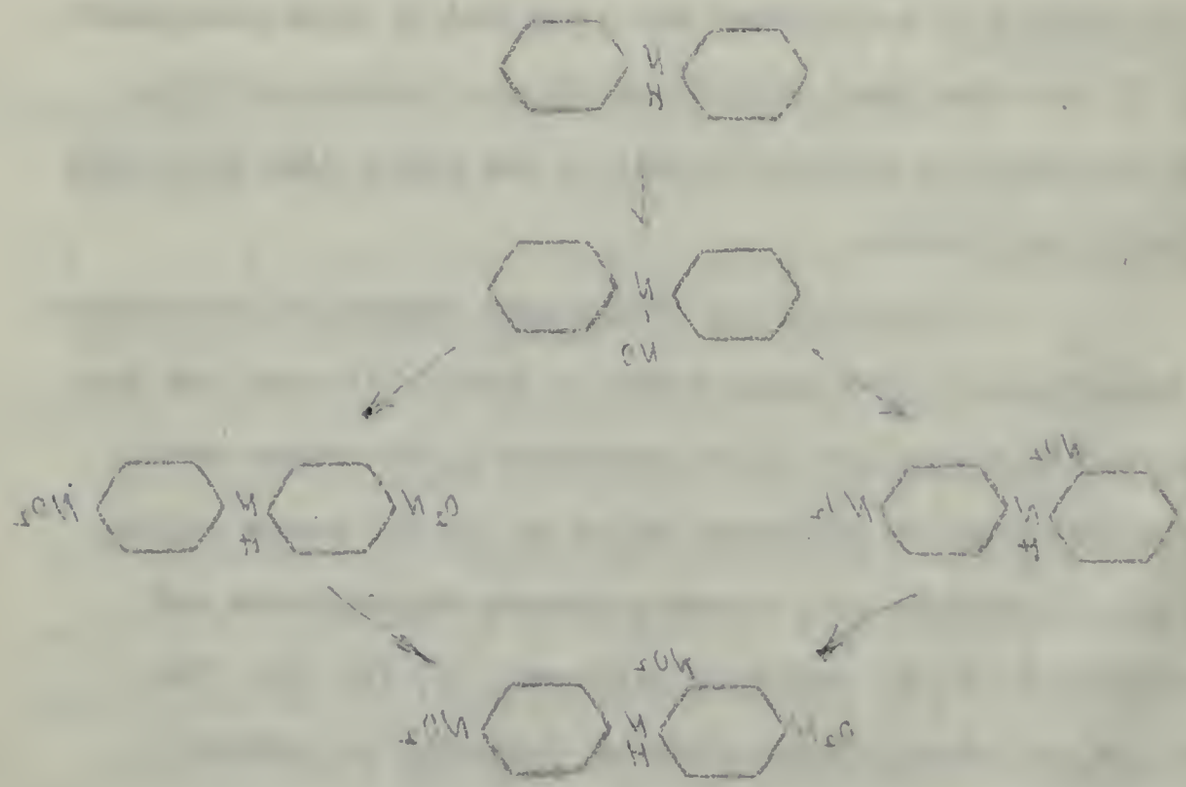
Researchers had others have studied the derivatives of diphenylcarbazone which cause powder to darken with age, and have concluded that they are due to impurities in the above used in the reader or to the oxidizing action of the air during drying and are not products of a reaction between diphenylcarbazone and diphenylcarbazide or the oxides of nitrogen. (4) (5) (6). The economical substitution problem involving balancing in diphenylcarbazone chemicals.

New experimentation underway in diphenylcarbazone

As a result of the investigations of the powder have been started

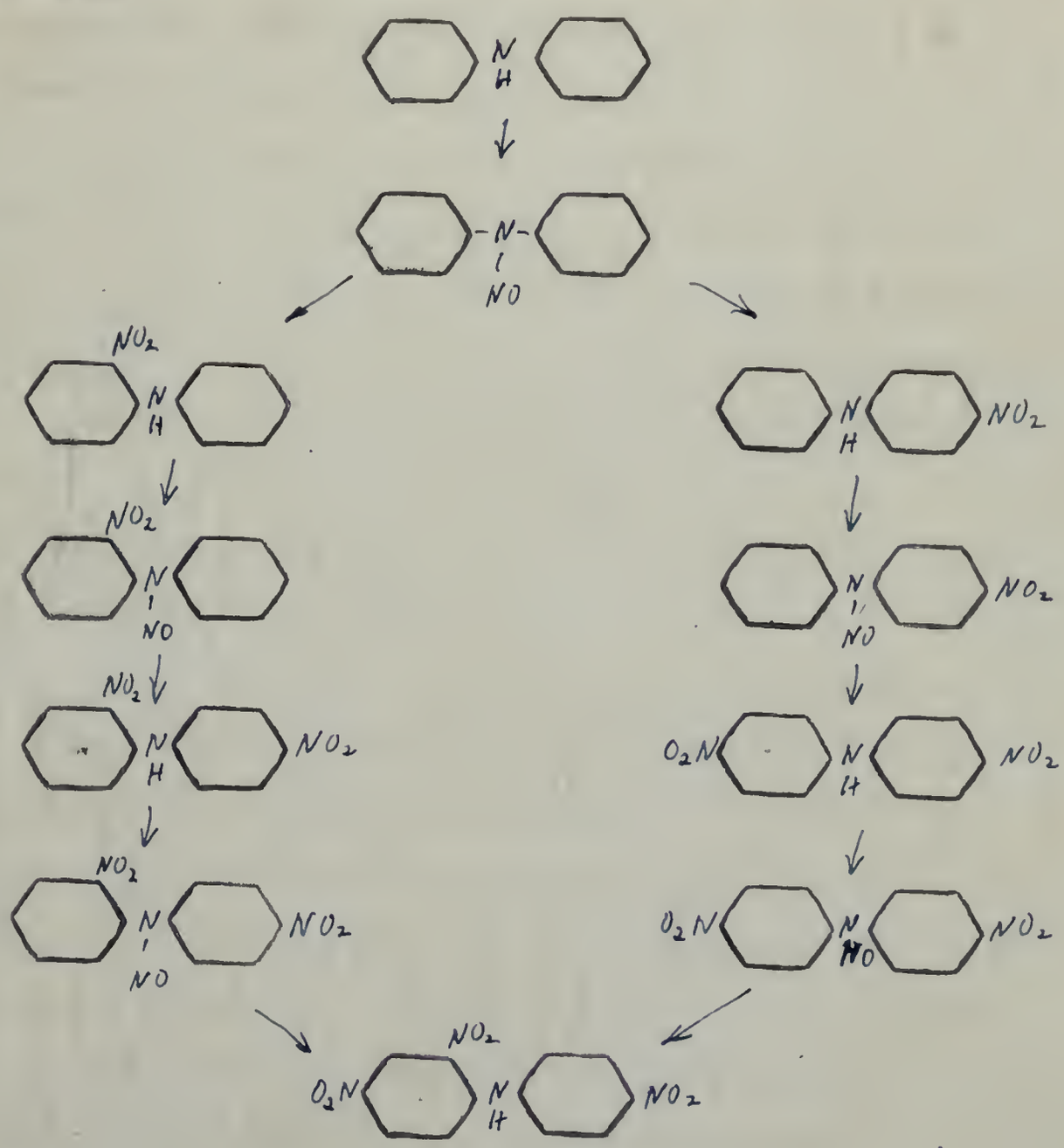
by several investigators and seem to be fairly well established. The chief work in this field was done by Davis and Ashdown at M. I. T., working under a contract for the U. S. Army. (9) (10) They prepared all the compounds which might be expected to be formed by nitration of diphenylamine and devised color tests to indicate the presence of each of them, as well as methods of separating each from mixtures of one another and nitrocellulose. These separations and tests were applied to diphenylamine-stabilized powders in various stages of decomposition, the most advanced being a powder that had been giving off fumes for several months. These tests indicate that the reactions are as follows:

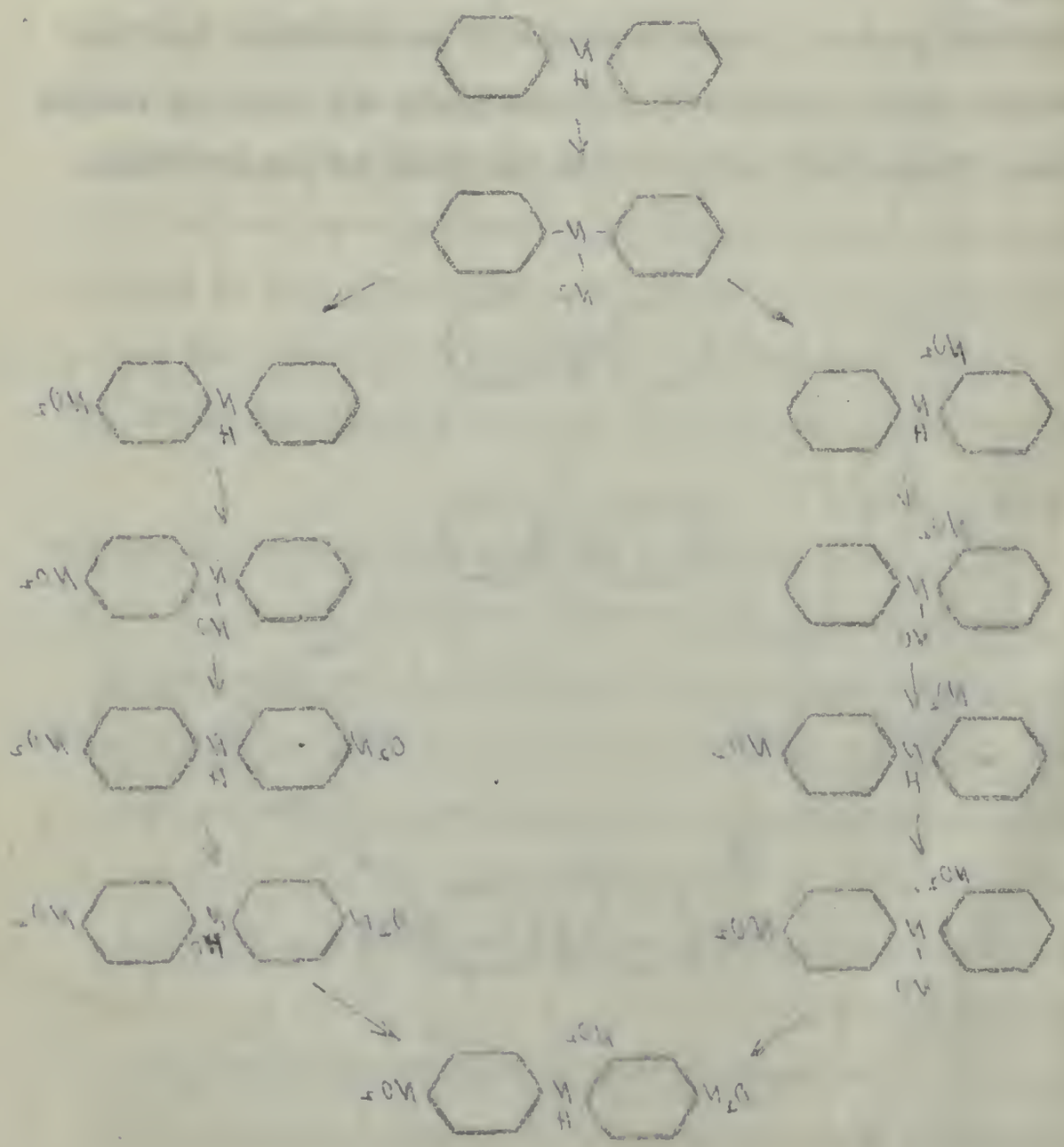




The last product formed, 2-4-4' trinitrodiphenylamine, might be expected to undergo further nitration to the 2-4-2'-4' tetranitro compound, but rather exhaustive attempts to isolate this compound were not successful.

Becker and Hunold, (11), confirm the fact that the tetranitro product is not formed. They also isolated several more intermediate compounds. Their proposed reactions are as follows:





The two mechanisms lead to the same end product, a trinitro derivative. The fact that diphenylamine takes up three nitro groups per molecule is one of the reasons that the compound is such a good stabilizer.

Becker and Hunold also measured the relative time required for the formation of the various compounds from powder containing diphenylamine, which was kept at 100° C. The nitrosamine was detected even before heating, the mononitro compound after one day at the elevated temperature, the dinitro after two days and the trinitro after four days.

They also tested the stabilizing power of the various intermediates by preparing powders containing each of these compounds. The relative values were as might be expected, except that the last product, the trinitro compound, was a better stabilizer than the compounds immediately preceding it, the dinitro diphenylnitrosamines. Since neither of these actually takes up any more nitrogen, it is hard to see how either can act as a stabilizer. No explanation was offered.

There is some evidence that the reaction is not as simple as the above discussion might indicate. The effect of temperature has been largely ignored in both the above experiments, but other workers have found that the reaction is apparently different at different temperatures. It was found (12) that stabilized powders decomposed at a rate which was only one-fifth to one-sixth that of unstabilized powder at 50° C., but at 77.5° C. its reaction rate was one-third that of the unstabilized powder.

This would indicate either that the reactions are different at different temperatures, or that the method of testing is inaccurate. The low-temperature test may not indicate the true velocity of decomposition.

It was also found (13) that a catalyst was necessary to carry out the reaction between diphenylamine and oxides of nitrogen in the laboratory. Chlorides and copper salts were used as catalysts. It is supposed that the small amounts of copper salts present in smokeless powder from the various manufacturing containers act as catalyst when the reaction occurs in powder.

It has also been observed that the purity of the diphenylamine and of the nitrocellulose affect the stability. (14) Powders made in 1912 with normally stabilized nitrocellulose and purified diphenylamine showed no loss of stability when tested after twenty years storage at room temperature, while powder manufactured during the first World War, using rapidly stabilized nitrocellulose and technical diphenylamine, showed marked losses of stability in fifteen years.

In this connection it is interesting to note that it is possible to restabilize powder with diphenylamine. The process (15) is performed by softening the powder in alcohol, without altering the grain size, and then re-impregnating with diphenylamine in alcohol solution.

Powder which has been stabilized with diphenylamine may be tested for stability and suitability for further use rather easily. A powder is considered unfit for further

storage if all of the diphenylamine and the diphenylnitrosamine have been exhausted. These compounds may be detected in an alcohol extract of the powder by simple color tests as follows:

If diphenylamine is present, a strip of filter paper on which an alcoholic extract of the powder has been allowed to dry is colored blue by a drop of ammonium persulfate. Also, if the extract contains diphenylamine it is colored blue by the addition of a few drops of a saturated solution of ammonium persulfate. Diphenylnitrosamine gives no color with ammonium persulfate, but imparts an intense blue color to a few milliliters of cold concentrated sulfuric acid.

Centralite

The first centralite was symmetrical dimethyl diphenyl urea. It was called centralite because it was developed at the Central War Laboratory in Germany. The ethyl compound, symmetrical diethyl diphenyl urea, usually called Centralite No. 1, is now more common; the methyl compound is now called Centralite No. 2.

The reaction of centralite with oxides of nitrogen has also been studied rather intensively, but opinion as to the nature of the reaction differs. One belief is that the reaction is simple nitration, forming first a dinitro compound with nitro groups substituted in the para positions of the two phenyl rings, and finally a tetranitro compound with two ortho and two para positions substituted (16). Another theory is that the centralite molecule is broken up, forming p-nitro phenyl ethyl

nitrosamine. (17) In either case, it should be noted that one centralite molecule takes up four nitro groups, which is one more than diphenylamine can absorb.

Other Compounds

Many other compounds have been used, or at least proposed, as stabilizers. Notmuch is known about the reactions they undergo, but a great many comparisons have been made as to the relative powers of stabilization. Some of the more important suggested substances are:

acardite (assymmetrical diphenyl urea)
alpha naphthyl urethane
camphor
carbazole
diamyl phthalate
diphenylbenzamide
ethyl oxinilate
mucic acid
naphthalene
nitro naphthalene
phenanthrene
potassium oxinilate
petrolatums of various kinds
phthalide
substituted urethanes
saccharic acid
tartaric acid

triacetate of methyl trimethylol methane (18)

triphenylamine

Comparison of Stabilizing Power

Many workers have made comparisons of the stabilizing power of various groups of the compounds listed above. However it is rather difficult to integrate the results, since methods differed widely and since each worker compared only a few compounds. The results of some of the more important experiments are given below:

Marqueyrol, in his work mentioned above, also made comparisons of the stabilizing power of several compounds. These included amyl alcohol, diphenylamine, nitronaphthalene, naphthalene, diphenyl benzamide, diphenyl nitrosamine, and carbazole. He, of course, concluded that diphenylamine was the best stabilizer, and it was his work that first promoted the use of this compound. However, he found that for some temperatures the benzamide was better, and he also found that carbazole, while not as good a stabilizer as diphenylamine, has less direct action on the nitrocellulose at high temperatures, and therefore can be used in larger quantities with safety.

Giua and Guastalla (19) ran comparative tests on several compounds. They concluded that the compounds under consideration could be arranged in order of decreasing stabilizing effect as follows:

Diphenylamine

Centralite

Aniline

alpha Naphthylurethane

Ethyl Oxinilate

Potassium Oxinilate

Phthalide

M. Tonegutti, (20) (21), found that diphenylamine and centralite were of equal power and were the best stabilizers of all he tested. Disubstituted urethanes were good stabilizers when mixed with acardite, but not alone, while phthalide and diamyl- and dibutyl-phthalates had no stabilizing action at all. Substances that are both stabilizers and gelatinizers gave very good results when mixed with substances which are stabilizers only, producing better stabilization than either substance used alone. Phenanthrene gave very good results on nitroglycerine powders. He concluded that diphenylamine is the best stabilizer for double-base powders, but acardite is the best for single-base powders.

Tonegutti also compared the stabilizing power of various petrolatums, since these were being seriously considered at that time. (22) As might be expected, it was found that those having the highest degree of unsaturation (as shown by the bromine number) were the best stabilizers.

R. Dalbert (23) compared powders containing 8.75 per cent of centralite with powders in which 2 per cent of the centralite had been replaced with either diphenylamine or carbazole. In each case, the straight centralite was the best,

Acetylene

Alpha Hydrogenation

Ethyl Cellulose

Polymeric Cellulose

Plasticizer

6. Pomeranz, (4.) (1921), found that acetylene-hydrogen mixtures of equal power and give the best physicians of all in cellulose. Concentrations varying from good stabilizers also stained with acetylene, but not alone, while propylene and ethyl- and dimethylacetylene had no stabilizing action at all. Unsaturated hydrocarbons with good stabilizers, especially when used alone also substances which are stabilizers only, producing further conditions than without substance used alone. Unsaturated oils with good results in nitrocellulose powders. In accordance with hydrogenation in the best stabilizers the conditions results, but acetylene is the best for single-base powders.

Bergdoll also compared the stabilizing power of various substances, some have been using mechanically mixed alcohol at least time. (5.) He states he especially in one level that using the highest degree of acetylene (as shown by the foreign system), have the best stabilizers.

7. Lehmann (12) compared powders containing 0.75 per cent of centralite with powders in which 2 per cent of the centralite had been replaced with diphenylamine or methylaniline. In each case, the stability measured by the test,

the carbazole being the worst.

Dalbert also studied the action of triphenylamine as a stabilizer, comparing its action to that of diphenylamine. (24) Powders containing two and five per cent of triphenylamine were compared with similar powders containing diphenylamine. The two-per cent powders showed similar action when heated to 100° C. but powder containing five per cent of triphenylamine showed less denitration than the corresponding diphenylamine powder. No nitroso compound was formed from the triphenylamine, the first product being a mononitro compound. These tests seem to indicate that triphenylamine might make a superior stabilizer, but apparently no further work has been done towards confirming this.

Krauz and Majrach considered the action of di- and tri- carboxylic acids, using tartaric acid as typical. Tartaric acid took up two nitro groups, forming dinitro tartaric acid. This compound when heated in aqueous solution decomposed into carbon dioxide, nitrogen trioxide, nitrogen, and a small amount of carbonic acid. If heated dry, the gases varied with temperature, glyoxalic acid being left in the solid residue. (25)

The same two workers also studied the nitro esters of other dicarboxylic acids, namely glutaric, mucic, and saccharic. These were found to act very much like tartaric acid, and to be better stabilizers than tartaric acid. (26)

Desmaroux (27) studied the comparative stabilizing effects of camphor and centralite, and concluded that camphor was

the industrial being too strong.

Gallant also studied the matter of delinquency as a possibility, concerning the method to that of delinquents. (34) Problems concerning the all time per year of delinquents were measured with ability problems concerning delinquents. The Binnet test popular, showed medium scores when tested to 120. But another experiment dare for such of delinquents showed that investigations that the corresponding delinquents question. In spite of this research was showed that the delinquents the first problem being a consideration proposed. These tests were to indicate that delinquents might make a regrettably educated, but apparently no further work has been done towards conditions this.

Crime and criminal punishment the matter of delinquent problem, makes delinquents would be typical. Terrible and land by the state groups, showing that the delinquents work. This research when carried in numerous activities incorporated take various months, groups lineaments, attempts and a small amount of economic work. It looked for, the gangs working with homemakers, physicals and being work in the social problem. (35) The cause for making this against the gangs across of other dissatisfaction works, mainly physicals, work, and economic. These were found to and very much like physicals work, and to be better adjusted than non-gangs work. (36)

Thomas (37) studied the occupations establishing effects of heredity and individuality, and concluded that employer was

as good as centralite, at least for periods up to 600 days, which was the longest test conducted.

Testing for Stability of Powder

No really satisfactory method of testing the stability of smokeless powder has as yet been devised. For research problems, such as comparing the stabilizing effect of various substances, the reduction in nitrogen content is taken as a measure of instability. Thus to compare two stabilizers, powders containing each are prepared, and rather large samples of each kept under carefully controlled conditions of temperature and humidity for a long time. From time to time, samples of each are withdrawn and analysed for nitrogen, the powder which has lost the least being considered the better stabilized. This method presents several difficulties and is really not very satisfactory. The nitrocellulose must be removed from the stabilizer and its products and tested for its nitrogen content. This presents difficulties and the method employed varies with the type of powder and the stabilizer. In addition, as has been mentioned before, the temperature plays an important part in the effective stability, some substances acting as very good stabilizers at one temperature but being very poor at other temperatures either higher or lower. Accordingly, such tests should be run at several temperatures.

Several methods have been used for testing stability without waiting for the actual decomposition to occur, as in the above tests. These are usually referred to as

as good as conditions at least for periods up to 300 days, which are the longest test conditions.

Specific Test Conditions of Interest

In public utilities review of testing the stability of conditions under for is you been conducted. For instance, questions, such as because is the neutralizing effect of various pollutants, are considered in a storage chamber in terms in a machine or testing. Then in summary for stabilizers, results concerning cases are previously are matter large analysis of some kept water accurately individual variations of temperature and humidity for a long time. Then then to time, results of each are although the analyses are determining the product which has been the least being substituted the further stabilizers. This which provide without distinctions and to results and very stabilizers. The determinations must be assumed from the stabilizer and the product and tested for the storage conditions. This presents qualifications and the without negligent testing with the type of product and the stabilizers. In addition, as has been mentioned before, the temperatures vary on increasing with to the stabilizing stability. Some information exists in very good stabilizers in our laboratories but being very poor at other temperatures which higher or lower. Accordingly, such tests should be run at several temperatures.

Several methods have been used for testing stability without waiting for the natural decomposition to occur, as in the above tests. These are usually referred to as

"heat tests". The two most common of these in this country are the 65.5° C. KI starch test and the 134.5° C. methyl violet test.

In the KI starch test, the powder samples are heated in test tubes at 65.5° C. Within each tube, a strip of KI starch paper, spotted with a 50 per cent aqueous solution of glycerine, is hung from a platinum hook. The tubes are stoppered with cork. The tubes are examined constantly and the time required for the first appearance of color on the paper is reported. Specifications in the United States call for at least 35 minutes before the first appearance of color.

In the methyl violet test, long tubes of heavy glass are used. They are closed loosely with notched corks, and are heated for almost their whole length in a bath at 134.5° C. The sample occupies about two inches of the lower end of the tube, and strips of methyl violet paper are placed about one inch above the sample. Times are noted for the paper to be turned completely to a salmon-pink color, for the first appearance of red fumes, and for explosion. Explosion usually does not occur for about five hours.

It will be noted that neither of the above gives a true indication of stability, since they measure the time for the self-catalyzed reaction in an atmosphere of air or red fumes. They thus serve only to compare the stability of powders which are similar in other respects. For true observations of stability, a heat test under vacuum is necessary.

"Small Lecture". The two-week course of lessons is full laboratory use plus 24,"7 h. If classes that and the 7.5,"7 h. weekly visits tests.

In the 12 school week, the product manufacture was begun in that class at 24,"7 h. Students said that, a study of 27 system paper, resulted with a 36 per cent improvement indicating of efficiency, in that first a pilotless test. The notes are observed all year. The notes are evaluated knowledgably and the time required for the final experiments of model in the paper is important. Investigations in the Bailed Tutorial call for 18 hours 30 minutes before the first experiment of model.

In the weekly studies week, long hours of heavy plant use week. The are closed lessons, all students traffic and are limited for element study which length in a week 24 7.5,"7 h. The sample decision about the factor of the lower and or the week, and effects of making student paper are planned given the lower class the lecture. Times are added for the paper to be lesson successfully to a satisfactory value, for the final experiment of the fuses, and the equipment. Experiments usually done not waste for about five hours.

It will be noted that students of all those giving a high indication of reliability, since they measure the time the mechanical-technical training is an adjustment of air or not times. They have error only to compare the stability of product model are similar to other students. The time measurements of reliability a lower test model tubes is necessary.

Effects of Temperature and Humidity on Stability

If smokeless powder is exposed to a humid atmosphere, it will absorb moisture slowly. Conversely, it will give up moisture to a dry atmosphere. The extent of both of these is dependent on the amount of surface moisture present originally in the powder, as mentioned above. The hygroscopicity also seems to depend on the total amount of nitrocellulose present, so that double base powders are less hygroscopic than straight nitrocellulose powder.

The amount of moisture present has a very marked effect on the stability. In one experiment a powder was exposed to a saturated atmosphere for three months at 50° C. After this exposure, it was kept at 65.5° C. in a closed container, red fumes appearing after nine days. The same powder, unexposed to the humid atmosphere, took 540 days to produce red fumes under the same conditions. (28)

Changes in temperature and humidity affect the stability of powder in another fashion, also. As the powder takes up moisture, the water and volatile matter in the powder move inward from the surface toward the interior. If the same powder then loses water, due to a change in conditions, this water moves outward. Thus there is a constant shifting of the liquid within the powder. This tends to break up the structure of the grain and promote decomposition.

Smokeless powder deteriorates much more rapidly at high than at low temperatures. This is due partly to the

acceleration of the decomposition reaction of nitrocellulose and partly to the fact that the stabilizer also decomposes at high temperatures. Diphenylnitrosamine decomposes very easily as the temperature is raised, and hence the stability of diphenylamine powders decreases rapidly.

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